plant models, it is difficult to understand or predict the impact of several pests occurring simultaneously on a crop. The development of the alfalfa weevil/alfalfa plant model illustrates one procedure which can be followed to obtain a systems dynamics model. The first step involved developing a flow diagram that included compartments for each component of the system and arrows connecting compartments to represent flows of materials or information. The diagram reflected our understanding of cause-effect relationships among components of the system. The next step involved writing equations for each component in the diagram. These equations were based on data from the literature and laboratory experiments, wherever possible, and described population processes and events in terms of rate functions for oviposition, mortality, development and feeding. By this time, several gaps in our knowledge had been revealed, and research was initiated to quantify the duration of diapause, adult longevity, and several other factors. The next step was to compare the model's performance, especially predictions of density versus time, with sampling data from field populations. When discrepancies were discovered, an effort was made to refine the faulty section of the model. In most cases, additional biological research was required to develop the necessary understanding, but at times an unsupported hypothesis was used with some success. For example, the model describes weevil oviposition rate as a function of stored food reserves that are depleted during winter and that must be restored to a minimum level in the spring before egg-laying can commence. We have no data to support the food reserve hypothesis, but after it was added to the model, the predicted spring egg densities agreed much better with the field data.

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ENVIRONMENTAL PARAMETERS AND THEIR USE

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Most current insect development models predict the timing of developmental stages by heat unit accumulation. Simple linear heat units ("degree-day") are usually assumed although more complicated non-linear units may be necessary. Degree-days may be *approximated* by accumulating average daily temperatures above a threshold, but a more accurate method is to accumulate half-day areas under sine wave curves between thresholds. This method allows for different minima at each end of the daily temperature cycle, and regression methods can be used to correct for bias in different geographic areas.

When the dependent variable has no obvious zero time point or when the process is obviously multi-variate, then other methods are necessary. An exponential model with a time-dependent rate is one approach having a multiple linear regression solution. The exponential equation takes the form

$$x_t = x_0 \exp\left[-\int_0^t f(t)dt\right]$$

where $f\ (t)$ is a linear sum of several cumulative time-dependent variables such as temperature, rainfall, vapor pressure deficit, etc. Taking logarithms to the base e gives:

$$\ln(x_t/x_0) = a_0 + a_1\int f_1(t)dt + \ldots. + a_n\int f_n(t)dt,$$

a multiple linear regression of ln (x_t/x_0) on accumulated variables (e.g. heat units, cum. rainfall, etc. Similar reasoning can be applied to "logistic" equation,

$$p = 1/\{1 + \exp\left[-\int f(t)dt\right]\},$$

where p is a proportion in some growth or mortality process. This equation may be linearized as

$$\ln[(1-p)/p] = a_0 + a_1\int f_1(t)dt + \ldots. + a_n\int f_n(t)dt$$

which is a multiple linear regression of $\ln[(1-p)/p]$ on accumulated environmental variables.

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DETERMINING ECONOMIC RELATIONSHIPS

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The term "action level" is proposed for general use as the estimate of the economic threshold. It might be defined as an empirically determined pest density at which some action tactic should be employed to prevent losses unacceptable to the producer or his decision-maker. "Action level" could thus be used to describe the pest densities at which management decisions are being made in most of our fledgling management programs. However, the continuing goal of pest management researchers should be to obtain the definitive economic thresholds and economic injury levels.

Some of the factors which should be considered in establishing economic thresholds include climatic conditions, phenological events, cultivars, crop cultural practices, economics, externalities, aesthetics, cumulative damage by all pests, plant compensation, insecticide resistance, geographical distribution of pests, produce quality, soil types, spatial dispersion, pest dispersal, natural mortality factors and pest density.